Reduction of Active and Reactive Power Losses on Transmission Lines using SSSC

J.I Uzor[1], D. C. Oyiogu[2], C.O. Ikaraoha[3]

[1]*Department of Electrical Engineering, Temple Gate Polytechnic Aba, Nigeria*

[2]*Department of Electrical Engineering, Nnamdi Azikiwe University Awka, Nigeria*

[3]*Department of Electrical Engineering, Nnamdi Azikiwe University Awka, Nigeria*

DOI: https://doi.org/10.51584/IJRIAS.2023.8411

Received: 24 March 2023; Revised: 07 April 2023; Accepted: 12 April 2023; Published: 01 May 2023

Abstract: This paper discusses a comprehensive study on reduction of power (active and reactive) losses in transmission lines using a second generation FACTS device, Static Synchronons Series Compensator (SSSC). Modern restructured power systems sometimes operate with heavily loaded lines resulting in power losses and higher voltage deviations, which may lead to mal-operation of power system and eventual collapse of the system. This is mainly due to continuous and uncertain growth in demand for electrical power. The paper presents a methodology to solve the problem of power losses in the Nigerian 28 – bus power system by incorporating Static Synchronons Series Compensator in the network using Newton-Rahson power flow algorithm. Simulation of power flow solution without and with the FACTS device was done using a Matlab software. The results showed that the maximum power (active and reactive) loss in the system without SSSC occurred in the transmission line connecting bus 17 (Jebba) to bus 23(Shiroro) and a 19.32% loss reduction was obtained on the line after the incorporation of the SSSC FACTS device giving a power saving of 80.68%. The total system active and reactive power losses before the application of SSSC was 205.183MW and 1594.683MVAR respectively. However, when the FACTS device was applied at the weak buses the total system active and reactive power losses reduced to 144.571MW and 1136.863MVAR respectively giving a percentage loss reduction in active and reactive power of 29.54% and 28.71% respectively resulting in a power saving of 70.46% and 71.29%. Hence, more power was available in the network when compared to the base case due to the installation of SSSC. Also an improvement in the voltage magnitude at the weak buses and other buses were noticed as they were all maintained at 1.0 PU.

I. Introduction

Background Information

Most bulk electric power is generated, transmitted and consumed in an alternating current (AC) system. Elements of alternating current system produces two kinds of power: real or active power (measured in Watts) and reactive power (measured in Volts Ampere Reactive or Var). Active power accomplishes useful work (eg. Running of motors and lighting of lamps). While reactive power supports the voltage that must be controlled for system reliability.

Utilities are experiencing more losses in the system with the growth of demand. The transformer loads and other power flow regulating devices have their own internal losses but they are smaller fraction of the total transmission system losses. These losses limits the desired transmission line power flows, cost millions and affect the economical operation of the deregulated utility environment.

Considering the utility loss percentage and its other consequences, the reduction of losses in even a small percentage will lead to the achievement of economical operation and better system efficiency[1]. The transmission line impedances generate and absorb reactive power and limits the active power flow. Hence reducing or compensating the transmission line impedances will regulate the reactive power flow and improve the active power flow through the line.

In the Nigerian context, the existing power network infrastructure is aging and very weak hence it is faced with many problems. One of such problems was the inability of the existing transmission lines to wheel more than 4,000 MW of power at its operational problems [2]. Most of the researchers that worked on the existing network recommended that the network be transformed from radial to ring because of the high losses inherent in it and the violation of allowable voltage drop of $\pm$5% of norminal value[3].

As a result of high demand on the existing and aging infrastructure, there is need to increase the transmission strength by building more power stations and transmission lines which will be very expensive to execute [4] . Hence it becomes imperative to device a means to ensure that the available generated power was transmitted to the load centers with minimum power losses on the lines. Although conventional control of power flows used to be done using generator control and voltage regulation using phase-shifting

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

and tap-changing transformer [5] .These challenges could be addressed more efficiently using advances in power electronic technologies such as the use of flexible alternating current transmission system (FACTS).

Flexible AC transmission system is fast developing solid-state technology that utilizes high power semiconductor device to control the reactive power flow and thus enhance the active power flow in the transmission lines so that the AC power can be transmitted across long distance efficiently[6]. This research work demonstrates the use of Static Synchronous Series Compensator, a second generation FACTS device, to reduce active and reactive power losses on transmission lines. With the application of this device, bus voltage magnitudes and power flow along the transmission lines can be more flexibly controlled.

Design of SSSC

SSSC is a power quality fact device that employs a VSC connected in series to a transmission line through a transformer. It can be used to supply voltage either 90^0 lagging or leading the line current. It controls the power flow in a transmission line by varying the magnitude and polarity of the reactive voltage injected in series with the line. When the SSSC injects voltage that leads the line current, it is equivalent to a capacitive reactance connected in series with the line power and it increases the line current as well as the power flow. SSSC consists of a coupling transformer, a GTO VSC and a DC circuit. It acts as a controllable voltage source whose voltage magnitude can be in an operating area controlled independently of the line current.

II. Methodology

For the purpose of steady-state network assessment, power flow solutions are probably the most popular kind of computer-based calculations carried out by planning and operation engineers. The reliable solution of power flows in real-life transmission and distribution network is not a trivial matter and over the years, owing to its very practical nature, many calculation methods have been put forward to solve this problem. Among them, Newton-Raphson methods, with their strong convergence characteristics have proved the most successful and have been embraced by power industry[7]. Thorough grounding on conventional power flow theory with practical reference to the Newton-Raphson method is provided and adopted for this work.

This technical research work is populated with efficient and elegant solutions for accommodating models of controllable equipment namely SSSC FACTS controller into the Newton-Raphson power flow algorithms. The modeling approach used to represent controllable equipment can be broadly classified into two main categories, namely, sequential and simultaneous solution methods. The former approach is amenable to easier implementations in Newton-Raphson algorithms.

However, its major drawback is that the bus voltage magnitude and angles are the only state variables that are calculated in true Newton-Raphson, and a sub-problem is formulated for updating the state variables of the controllable device at the end of each iteration thus such an approach yields no quadratic convergence.

Alternatively, the Unified approach combines the state variables describing controllable equipment with those describing the network in a single frame of reference for unified iterative solutions using the Newton-Raphson algorithm [8]. The method retains Newton`s quadratic convergence characteristics. The unified approach blends the alternating current (AC) network and power system controller state variables in single system of simultaneous equations viz:

$$F(X_{nAC}, R_{AF}) = 0 \quad (1)$$

$$g(X_{nAC}, R_{nF}) = 0 \quad (2)$$

Where X_{nAC} stands for the AC network state variables namely nodal voltage magnitude and phase angles and R_{nF} stands for the power system SSSC controller state variable.

The line data of Nigeria 28 bus power network obtained from Transmission Company of Nigeria as indicated in table 1, bus data of the Nigeria 28 bus power network indicated in table 2, Building upon the basic principles of steady-state operation and modeling of FACTS controller, the power flow theory reference to Newton-Raphson method is detailed. Furthermore key aspects of modeling implementation of FACTS controllers are presented and applied in the linearized frame of reference to incorporate Newton-Raphson power flow algorithm using SSSC controller. Two different power flow programs of the Nigerian 28-bus power system network were written in Matlab environment viz: Matlab program to calculate positive sequence power flows using the convectional Newton-Raphson method and Matlab program to incorporate the static synchronous series compensator (SSSC) FACTS controller within the Newton-Raphson power flow algorithm.

Finally the results of the programs were used to assess how the FACTS controller (SSSC) controls the power flow, reduces the active and reactive power losses and improves the voltage profile of the Nigerian 28-bus power system network.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

Basic Formulations

A popular approach to assess the steady operation of a power system is to write equations stipulating that in a given bus the generation, load and power exchange through the transmission elements connecting to the bus must add up to zero. This applies to both active and reactive power. These equations are termed mismatch power equations and at bus k they take the following form as depicted in equations 3 and 4 respectively;

$$\Delta P_K = P_{GK} - P_{LK} - P_K^{cal} = P_K^{sch} - P_K^{cal} = 0 \quad (3)$$

$$\Delta Q_K = Q_{GK} - Q_{LK} - Q_K^{cal} = Q_K^{sch} - Q_K^{cal} = 0 \quad (4)$$

The termsΔP_K and ΔQ_K are the mismatch active and reactive powers at bus k, respectively, P_{GK} and Q_{GK} represent respectively, the active and reactive powers injected by the generator at bus k.

For the purpose of the power flow solutions, it is assumed that these variables can be controlled by the power plant operator. P_{LK} and Q_{LK} represent the active and reactive powers drawn by the load at bus k, respectively. Under normal operation the customer has control of these variables, and in the power flow formulation they are assumed to be known variables. In principle, at least, the generation and the load at bus k may be measured by the electric utility and in the parlance of power system engineers, their net values are known as the scheduled active and reactive powers.

$$P_K^{sch} = P_{GK} - P_{LK} \quad (5)$$

$$Q_K^{sch} = Q_{GK} - Q_{LK} \quad (6)$$

The transmitted active and reactive powers, P_K^{cal}andQ_K^{cal} are functions of nodal voltages and network impedances and are computed using the power flow equations. Provided the nodal voltages throughout the power network are known to a good degree of accuracy the transmitted powers are easily and accurately calculated. In this situation, the corresponding mismatch powers are zero for any practical purpose and the power balance at each bus of the network is satisfied.

However, if the nodal voltages are not known precisely then the calculated transmitted powers will have only approximated values and the corresponding mismatch powers are not zero. The power flow solution takes the approach of successively correcting the calculated nodal voltages and hence, the calculated transmitted powers until values accurate enough are arrive at, enabling the mismatch power to be zero or fairly close to zero. In modern power flow computer programs, it is normal for all mismatch equations to satisfy a tolerance as tight as 1e-12 before the iterative solution can be considered successful.

Upon convergence, the nodal voltage magnitudes and angles yield useful information about the steady state operating conditions of the power system and are known as state variables. In order to develop suitable power flow equations, it is necessary to find the relationship between injected bus current and bus voltages.

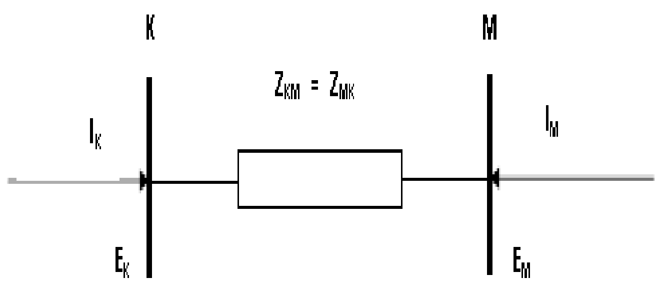

Fig 1: Equivalent impedance

Based on figure 1 the injected complex current at bus k, denoted by I_K, may be expressed in terms of the complex bus voltages E_K and E_M as presented in equation 7

$$I_K = \frac{1}{Z_{KM}} x (E_K - E_M) = Y_{KM} x (E_K - E_M) \quad (7)$$

Similarly for bus M,

$$I_M = \frac{1}{Z_{KM}} x (E_M - E_K) = Y_{KM} x (E_M - E_K) \quad (8)$$

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

The above equation can be written in matrix form as shown in equation 9 below

$$\begin{bmatrix} I_K \\ I_M \end{bmatrix} = \begin{bmatrix} y_{km} & -y_{km} \\ -y_{mk} & y_{mk} \end{bmatrix} \times \begin{bmatrix} E_k \\ E_m \end{bmatrix} \quad (9)$$

In compact form, equation 9 is re-written as shown in equation 10

$$\begin{bmatrix} I_K \\ I_M \end{bmatrix} = \begin{bmatrix} y_{KK} & y_{KM} \\ y_{MK} & y_{MM} \end{bmatrix} \times \begin{bmatrix} E_k \\ E_m \end{bmatrix} \quad (10)$$

Where the bus admittance and voltages can be expressed in more explicit form as shown below

$$Y_{ij} = G_{ij} + jB_{ij} \quad (11)$$

$$E_i = V_i e^{-j\theta i} = V_i(cos\theta_i + jsin\theta_i) \quad (12)$$

Where I = k, m and j = k, m

The complex power injected at bus k consist of an active and reactive component and may be expressed as a function of the nodal voltage and the injected current at the bus:

$$S_K = P_K + jQ_K = E_K I_K^* = E_K(Y_{KK}E_K + Y_{KM}E_M) * \quad (13)$$

Where I^*_K is the complex conjugate of the current injected at bus k.

The expressions for the P_K^{cal} and Q_K^{cal} can be determined by substituting equations 11 and 11 into 13 and separating into real and imaginary parts gives rise to equations 14 – 15.

$$P_K^{cal} = V_K^2 G_{KK} + V_K V_M[G_{KM}\cos(\theta_k - \theta_m) + B_{KM}\sin(\theta_k - \theta_m)] \quad (14)$$

$$Q_K^{cal} = -V_K^2 B_{KK} + V_K V_M[G_{KM}\sin(\theta_k - \theta_m) - B_{KM}\cos(\theta_k - \theta_m)] \quad (15)$$

For specified levels of power generation and power load at bus k, and according to equations 3 and 4, the mismatch equations may written down as follows:

$$\Delta P_K = P_{GK} - P_{LK} - \{V_K^2 G_{KK} + V_K V_M[G_{KM}\cos(\theta_k - \theta_m) + B_{KM}\sin(\theta_k - \theta_m)]\} \quad (16)$$

$$\Delta Q_K = Q_{GK} - Q_{LK} - \{V_K^2 B_{KK} + V_K V_M[G_{KM}\sin(\theta_K - \theta_M) - B_{KM}\cos(\theta_K - \theta_M)]\} \quad (17)$$

Similarly equations may be obtained for bus M simply by exchanging subscripts K and M in equation 16 and 17. It should be remarked that equations 14 and 15 represent only the powers injected at bus K through the i[th] transmission element, that is P_K^{cal} and Q_K^{cal}.

However, a practical power system will consist of many buses and many transmission elements. This calls for equations 14 and 15 to be expressed in more general term, with the net power flow injected at bus K expressed as the summation of the powers flowing at each one of the transmission elements terminating at this bus. This is illustrated in figure2 for cases of active and reactive power respectively.

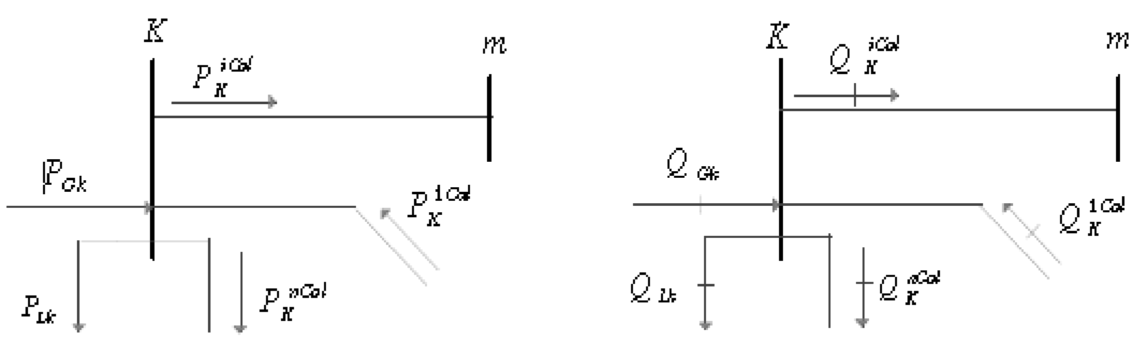

Figure 2: Power balance at bus K for active and reactive component.

The generic net active and reactive power injected at bus K are given as follows:

$$P_K^{cal} = \sum_{i=1}^{n} P_K^{cal} \qquad (18)$$

$$Q_K^{cal} = \sum_{i=1}^{n} Q_K^{cal} \qquad (19)$$

Where P_K^{cal} and Q_K^{cal} are computed by using 14 and 15 respectively. As an extension, the generic power mismatch equations at bus k are given as follows:

$$\Delta P_K = P_{GK} - P_{LK} - \sum_{i=1}^{n} P_K^{cal} = 0 \qquad (20)$$

$$\Delta Q_K = Q_{GK} - Q_{LK} - \sum_{i=1}^{n} Q_K^{cal} = 0 \qquad (21)$$

Power Flow

A power flow study (also known as load-flow study) is an important tool for determining the state of the system. It involves numerical analysis applied to a set of non-linear equations that describe the state of the power systems. Power flow studies are important because they allow for planning and future expansion of existing power systems. A power flow, also, can be used to determine the best and most effective design of power systems. The object of power flow study in this work is the determination of bus voltage magnitudes and corresponding angles as well as power flows for specified generation and bus conditions.

Power flow control

The power transmission line can be represented by a two-bus system “k” and “m” in ordinary form [9]. The active power transmitted between bus nodes k and m is given by:

$$P = \frac{V_m V_k}{X} Sin(\delta_k - \delta_m) \qquad (22)$$

WhereV_k and V_m are the voltages at the nodes, ($\delta_k - \delta_m$) the angle between the voltages and X, the line impedance. The power flow can be controlled by altering the voltage at a node, the impedance between the nodes and the angle between the end voltages. The reactive power is given by:

$$Q = \frac{V_m - V_k}{X} (1 - Cos(\delta_k - \delta_m)) \qquad (23)$$

Steady State Modeling Assumptions with Sssc

For ideal steady state analysis the following modeling assumption are applied to gain the equivalent circuits of the SSSC FACTS controller.

1. Active power exchange (PE) between the ac system and the SSSC is neglected.
2. Harmonics generated outside of the fundamental harmonic by the controller are all neglected.
3. The system and the controller are three phase balance at all times.

State Variable Initialization

The effectiveness of the Newton-Raphson method to achieve feasible iteration solution is dependent upon the selection of suitable initial values for all the state variables involved in the study. The power flow solution of networks that contain only conventional components is normally started with voltage magnitudes of 1 p.u (per unit) at all buses. The slack and the PV buses are given their specified values, which remain constant throughout the iterative solution if no generator reactive power limits are violated. The initial voltage phase angles are selected to be 0 at all buses.

Generator Reactive Power Limits

Even though the mismatch reactive power equation of ΔQ_K of PV bus K is not required, solution of equation 19 for the PV bus is still carried out at each iterative step to assess whether or not the calculated power Q_K^{cal} is within the generator reactive power limits.

$$Q_{GminK} < Q_{GK} < Q_{GmaxK} \qquad (24)$$

If either the following conditions occur during the iterative process:

$$Q_K^{cal} \geq Q_{GmaxK} \qquad (25)$$

$$Q_K^{cal} \leq Q_{GminK} \qquad (26)$$

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

Depending on the violated limit, together with the relevant Jacobian entries the nodal voltage magnitudes at bus K is allowed to vary and V_K becomes a state variable. It should be remarked that bus K may revert to being a generator PV bus at some point during the iterative process if better estimates of Q_K^{cal} calculated with more accurate nodal voltages indicates that the reactive power requirements at K can after all be met by the generator connected at bus K. Hence, reactive power limit checking should start after the first or second iteration since nodal voltage values computed at the beginning of the iterative process may be quite inaccurate leading to misleading reactive power requirements. The switching of buses from PV to PQ and vice versa imposes additional numerical demand on the iterative solution and retards convergence[10].

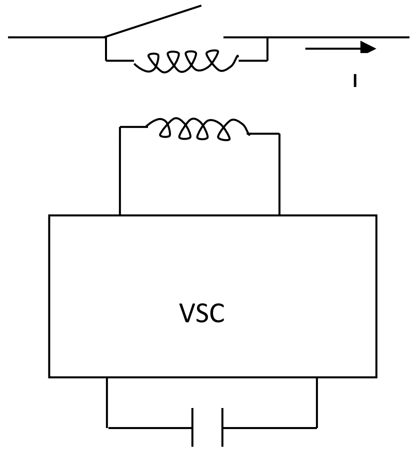

Figure 3: Schematic representation of SSSC

Basically, the SSSC consist of three components. A voltage source converter which is the main component, a transformer that couples the Static Synchronous Series compensator to the transmission line and an energy source that provides a voltage across a DC capacitor which compensates for the device losses. The Static Synchronous Series compensator is a series compensator. It has a voltage source converter serially connected to a transmission line through a transformer. It injects voltage in quadrature with one of the line end voltages in order to regulate active power flow. It does not draw reactive power from the AC system, it has its own reactive power provision in the form of a DC capacitor [11]. A block diagram representation of the SSSC is as shown in fig 3 above.

Steady state modeling of SSSC

The SSSC voltage source is given by the equation below

$$E_{CR} = V_{CR} (Cos\delta_{CR} + jSin\delta_{CR}) \quad (27)$$

The boundary condition for V_{cR} and δ_{cR} are as given in equations (28) and (29);

$$V_{cRmin} \le V_{cR} \le V_{cRmax} \quad (28)$$

$$0 \le \delta_{cR} \le 2\pi \quad (29)$$

The expression for the active and reactive powers at bus K are as in equations (30) and (31).

$$P_k = V_k^2 G_{kk} - V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] + V_k V_{cR} [G_{km} \cos(\theta_k - \delta_{cR}) + B_{km} \sin(\theta_k - \delta_{cR})] \quad (30)$$

$$Q_k = V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] + V_k V_{cR} [G_{km} \sin(\theta_k - \delta_{cR}) - B_{km} \cos(\theta_k - \delta_{cR})] \quad (31)$$

The active and reactive power relations for the converter are;

$$P_{cR} = V_{cR}^2 G_{mm} + V_{cR} V_k [G_{km} \cos(\delta_{cR} - \theta_k) - B_{km} \sin(\delta_{cR} - \theta_k)] + V_{CR} V_M [G_{km} \cos(\theta_k - \delta_{cR}) - B_{km} \sin(\theta_k - \delta_{cR})] \quad (32)$$

$$Q_{cR} = V_{cR}^2 B_{mm} + V_{cR} V_k [G_{km} \mathrm{Sin}(\delta_{cR} - \theta_k) - B_{km} \mathrm{Cos}(\delta_{cR} - \theta_k)] + V_{CR} V_m [G_{mm} \mathrm{Sin}(\delta_{cR} - \theta_m) - B_{mm} \mathrm{Cos}(\delta_{cR} - \theta_m)] \quad (33)$$

The linearized SSSC model is thus;

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

$$\begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\delta \theta_m} & \frac{\partial P_k}{\partial V_k}V_k & \frac{\partial P_k}{\partial V_m}V_m & \frac{\partial P_k}{\partial \delta_{CR}} & \frac{\partial P_k}{\partial V_{CR}}V_{CR} \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial V_k}V_k & \frac{\partial P_m}{\partial V_m}V_m & \frac{\partial P_m}{\partial \delta_{CR}} & \frac{\partial P_m}{\partial V_{CR}}V_{CR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial V_k}V_k & \frac{\partial Q_k}{\partial V_m}V_m & \frac{\partial Q_k}{\partial \delta_{CR}} & \frac{\partial Q_k}{\partial V_{CR}}V_{CR} \\ \frac{\partial Q_m}{\partial \theta_k} & \frac{\partial Q_m}{\delta \theta_m} & \frac{\partial Q_m}{\partial V_k}V_k & \frac{\partial Q_m}{\partial V_m}V_m & \frac{\partial Q_m}{\partial \delta_{CR}} & \frac{\partial Q_m}{\partial V_{CR}}V_{CR} \\ \frac{\partial P_{mk}}{\partial \theta_k} & \frac{\partial P_{mk}}{\delta \theta_m} & \frac{\partial P_{mk}}{\partial V_k}V_k & \frac{\partial P_{mk}}{\partial V_m}V_m & \frac{\partial P_{mk}}{\partial \delta_{CR}} & \frac{\partial P_{mk}}{\partial V_{CR}}V_{CR} \\ \frac{\partial Q_{mk}}{\partial \theta_k} & \frac{\partial Q_{mk}}{\delta \theta_m} & \frac{\partial Q_{mk}}{\partial V_k}V_k & \frac{\partial Q_{mk}}{\partial V_m}V_m & \frac{\partial Q_{mk}}{\partial \delta_{CR}} & \frac{\partial Q_{mk}}{\partial V_{CR}}V_{CR} \end{bmatrix}$$

Implementation

MATLAB based program was developed for the power analysis of the 28-bus `Nigerian 330 KV systems without and with steady state models of Static Synchronous Series Compensator (SSSC). The input data includes the basic system data needed for conventional power flow calculation, that is, the number and types of buses, transmission line data, generation and load data and the values of SSSC control parameters. System admittance matrix and conventional Jacobian matrix is formed due to incorporation of SSSC. At the next step, Jacobian matrix and mismatched power flow equations are modified. The bus voltages are updated at each iteration. Convergence is obtained and if no, Jacobian matrix is modified and power equations are mismatched until convergence is achieved. If yes, power flow results are displayed

Input Data

The transmission line data and the bus data of the Nigerian 330 KV 28-bus network used as a case study were collected from the Transmission company of Nigeria (TCN) as presented in tables 1 and 2 respectively. They were used to carry out the simulation analysis.

Table 1: Transmission line data of the Nigerian 28-network

From Bus	To BUS	Resistance R(p.u)	Reactance X(p.u)	Susceptance B(p.u)
3	1	0.0006	0.0044	0.0295
3	1	0.0006	0.0044	0.0295
4	5	0.0007	0.0050	0.0333
4	5	0.0007	0.0050	0.0333
1	5	0.0023	0.0176	0.1176
1	5	0.0023	0.00176	0.1176
5	8	0.0110	0.0828	0.5500
5	8	0.0110	00828	0.5500
5	9	0.0054	0.0405	0.2669
5	10	0.0099	0.0745	0.4949
6	8	0.0077	0.0576	0.3830
6	8	0.0077	0.0576	0.3830
2	8	0.0043	0.0317	0.2101
2	7	0.0012	0.0089	0.0589
7	24	0.0025	0.0186	0.1237

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

8	14	0.0054	0.0405	0.2691
8	10	0.0098	00742.	0.4930
8	24	0.0020	0.0148	0.0982
8	24	0.0020	0.0148	0.0982
9	10	0.0045	0.0340	0.2257
15	21	0.0122	0.0916	0.6089
15	21	0.0122	0.0916	0.6089
10	17	0.0061	0.0461	0.3064
10	17	0.0061	0.0461	0.3064
10	17	0.0061	0.0461	0.3064
11	12	0.0010	0.0074	0.0491
11	12	0.0010	0.0074	0.0491
12	14	0.0060	0.0455	0.3025
13	14	0.0036	0.0272	0.1807
13	14	0.0036	0.0272	0.1807
16	19	0.0118	0.0887	0.5892
17	18	0.0002	0.0020	0.0098
17	18	0.0002	0.0020	0.0098
17	23	0.0096	0.0721	0.4793
17	23	0.0096	0.0721	0.4793
17	21	0.0032	0.0239	0.1589
17	21	0.0032	0.0239	0.1589
19	20	0.0081	0.0609	0.4046
20	22	0.0090	0.0680	0.4516
20	22	0.0090	0.0680	0.4516
20	23	0.0038	0.0284	0.1886
20	23	0.0038	0.0284	0.1886
23	26	0.0038	0.0284	0.1886
23	26	0.0038	0.0284	0.1886
12	25	0.0071	0.0532	0.3800
12	25	0.0071	0.0532	0.3800
19	25	0.0059	0.0443	0.3060
19	25	0.0059	0.0443	0.3060
25	27	0.0079	0.0591	0.3900
25	27	0.0079	0.0591	0.3900

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

5	28	00016.	0.0118	0.0932
5	28	0.0016	00118.	0.0932

Table 2: Bus data of the Nigerian 28-bus system

Bus No	Bus code	Voltage Mag.	Angle Degree	---Load---- MW	Mvar	-----Generator---- MW	Mvar	Qmin	Qmax
1	1	1.050	0	68.9	51.7	0	0	-1006	1006
2	2	1.050	0	0	0	670	0	-1030	1000
3	0	1.000	0	274.4	205.8	0	0	0	0
4	0	1.000	0	344.7	258.5	0	0	0	0
5	0	1.000	0	633.2	474.9	0	0	0	0
6	0	1.000	0	13.8	10.3	0	0	0	0
7	0	1.000	0	96.5	72.4	0	0	0	0
8	0	1.000	0	383.3	287.5	0	0	0	0
9	0	1.000	0	275.8	206.8	0	0	0	0
10	0	1.000	0	201.2	150.9	0	0	0	0
11	2	1.050	0	52.5	39.4	431.0	0	-1000	1000
12	0	1.000	0	427.0	320.2	0	0	0	0
13	0	1.000	0	177.9	133.4	0	0	0	0
14	0	1.000	0	184.6	138.4	0	0	0	0
15	0	1.000	0	114.5	85.9	0	0	0	0
16	0	1.000	0	130.6	97.9	0	0	0	0
17	0	1.000	0	11.0	8.2	0	0	0	0
18	2	1.050	0	0.0	0.0	495.0	0	-1050	1050
19	0	1.000	0	70.3	52.7	0	0	0	0
20	0	1.000	0	193.0	144.7	0	0	0	0
21	2	1.050	0	7.0	5.2	624.7	0	-1010	1010
22	0	1.000	0	220.6	142.9	0	0	0	0
23	2	1.050	0	70.3	36.1	388.9	0	-1000	1000
24	2	1.050	0	20.6	15.4	190.3	0	-1000	1000
25	0	1.000	0	110.0	89.0	0	0	0	0
26	0	1.000	0	290.1	145.0	0	0	0	0
27	2	1.050	0	0.0	0.0	750.0	0	-1000	1000
28	2	1.050	0	0.0	0.0	750.0	0	-1000	1000

III. Results and Discussions

The results of the simulations carried out on the Nigerian 28-bus network without SSSC and the i

Results

Table 3: Tabulated power flow result without SSSC

Bus No.	Bus Name	Voltage P.U	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
1	Egbin	1.0500	0.0000	509.783	1192.667	68.900	51.700
2	Delta	1.0500	9.5573	670.000	61.095	0.000	0.000
3	Aja	1.0398	-0.5698	0.000	-0.000	274.400	205.000
4	Akangba	0.8776	-9.6842	0.000	0.000	344.700	258.500

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

5	Ikeja	0.8951	-8.5577	0.000	-0.000	633.200	474.900
6	Ajaokuta	1.0330	2.8575	-0.000	-0.000	13.800	10.300
7	Aladja	1.0458	8.1756	-0.000	-0.000	96.500	72.400
8	Benin	1.0171	3.4194	0.000	0,000	383.300	287.500
9	Ayode	0.8540	3.4194	0.000	0.000	275.800	260.800
10	Osogbo	0.9052	0.9052	0.000	-0.000	205.200	150.900
11	Afam	1.0500	-9.2351	431.000	565.050	52.500	39.400
12	Alaoji	1.0092	-10.4625	-0.000	-0.000	427.000	320.200
13	New Heaven	0.9885	-1.1479	-0.000	-0.000	177.900	133.400
14	Onitsha	1.0278	1.3468	-0.000	-0.000	184.600	138.400
15	Bimin-Kebbi	1.0097	0.9471	0.000	-0.000	114.500	85.900
16	Gombe	0.7646	-41.5509	0.000	0,000	130.600	87.900
17	Jebba	1.0433	0.1676	-0.000	-0.000	11.000	8.200
18	Jebba-GS	1.0500	0.6837	495.000	301.734	0.000	0.000
19	Jos	0.8700	-32.1753	-0.000	-0.000	114.000	90.000
20	Kaduna	0.8950	-330120	-0.000	-0.000	30.000	161.000
21	Kainji	1.0500	6.4669	624.700	-53.498	7.000	5.200
22	Kano	0.7393	-45.1711	0.000	-0.000	220.600	142.900
23	Shiroro	1.0500	-23.6568	388.900	848.830	70.300	36.100
24	Sapele	1.0500	6.1561	190.300	237.018	20.600	15.400
25	Calabar	0.9033	-23.2755	0.000	0.000	110.000	89.000
26	Katampe	1.003	-27.8936	0.000	0.000	290.100	145.000
27	Okpai	1.0500	4.0440	750.000	274.505	0.000	0.000
28	AES-GS	1.0500	7.4384	750.000	-40.677	0.000	0.000
Total				**4809.683**	**3386.724**	**4604.500**	**322.800**

Table 4.: Tabulated results of line flows and losses without SSSC

From Bus	To Bus	P MW	Q MVAR	From Bus	To Bus	P MW	Q MVAR	Line Losses	
								MW	MVAR
1	3	275.046	207.345	3	1	-274.400	-202.611	0.646	4.735
1	5	907.671	864.888	5	1	-874.879	613.955	32.792	250.933
1	28	-741.834	111.301	28	1	750.000	-14.327	8.166	96.974
2	7	299.205	12.667	7	2	-298.229	-5.427	0.976	7.240
2	8	370.795	78.085	8	2	-365.195	-36.800	5.600	41.185
4	5	-344.700	-255.935	5	4	346.375	267.901	1.675	11.968

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

5	8	-238.300	-76.251	8	5	246.895	140.944	8.595	64.693
5	9	130.056	77.232	9	5	-128.514	-65..667	1.542	11.565
5	10	3.548	-12.632	10	5	-3.527	12.792	0.021	0.160
6	8	-13.800	30.573	8	6	13.881	-29.965	0,081	0.607
7	24	201.729	-47.001	24	7	-200.748	54.297	0.981	7.296
8	14	88.410	-37.013	14	8	-97.931	40.609	0.480	3.597
8	24	-367.291	-168.425	24	8	370.448	191.785	3.157	23.360
9	10	-147.286	-105.204	10	9	149.307	120.475	2.021	15.271
10	17	-346.981	-200.008	17	10	358.920	290.242	11.940	90.234
11	12	378.500	531.063	12	11	-174.642	-502.517	3.858	18.546
12	14	-457.658	67.371	14	12	470.265	28.227	12.606	95.598
12	25	405.301	189.459	25	12	-391.347	-84.904	13.954	104.554
13	14	-177.900	-115.744	14	13	179.560	128.283	1.660	12.539
14	27	-746.494	-245.064	27	14	750.000	285.971	3.506	40.907
15	21	-114.500	-23.825	21	15	116.137	36.115	1.637	12.290
16	19	-130.600	-63.458	19	16	134.856	95.449	4.256	31.992
17	18	-494.389	-296.706	18	17	495.000	302.815	0.611	6.108
17	21	-494.258	64.720	21	17	501.563	-10.163	7.305	54.557
17	23	618.727	37.434	23	17	-594.842	217.062	33.886	254.495
19	20	26.573	-84.523	20	19	-26.065	87.344	0.508	2.821
19	25	-275.429	-7.443	25	19	281.347	51.879	5.918	44.437
20	22	230.914	196.142	22	10	-220.600	118.216	10.314	77.927
20	23	-586.849	-365.972	23	10	609.541	535.567	22.692	169.594
23	26	293.900	154.530	26	23	-290.100	126.129	3.800	28.402
Total								**205.183**	**1594.683**

Table 5: Tabulated power flow results with SSSC

Bus No.	Bus Name	Voltage P.U	Angle Degree	Generation		Load	
				MW	MVAR	MW	MVAR
1	Egbin	1.0500	0.0000	357.081	571.402	68.900	51.700
2	Delta	1.0500	12.4573	670.000	28.484	0.000	0.000
3	Aja	1.0398	-0.5698	0.000	-0.000	274.400	205.800
4	Akangba	1.0000	-7.9669	1.087	306.352	344.700	258.500
5	Ikeja	1.0000	-6.9620	8.026	173.044	633.200	474.900
6	Ajaokuta	1.0433	5.7356	-0.000	0.000	13.800	10.300

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

7	Aladja	1.0458	11.0796	0.000	0.000	96.500	72.400
8	Benin	1.0270	6.2899	0.000	0.000	183.300	287.500
9	Ayode	1.0000	-9.0226	6.903	200.688	275.800	206.800
10	Osogbo	1.0000	-5.4000	11.265	14.397	201.200	150.900
11	Afam	1..0500	-4.4709	431.000	397.251	52.500	39.400
12	Alaoji	1.0211	-5.7737	0.000	-0.000	427.000	320.200
13	New Heaven	1.0000	2.8579	11.235	21.892	177.900	133.400
14	Onitsha	1.0323	5.1881	0..000	-0.000	184.600	138.400
15	BiminKebbi	1.0097	5.7292	-0.000	0.000	114.500	85.900
16	Gombe	1.0000	-30.2853	10.873	61.609	130.600	97.900
17	Jebba	1.0470	4.9449	0.000	0.000	11.000	8.200
18	Jebba-GS	1.0500	5.4499	495.000	102.875	0,000	0.000
19	Jos	1.0000	-24.0352	11.287	1.779	114.000	90.000
20	Kaduna	1.0000	-24.7163	11.283	-5.798	182.000	161.000
21	Kainji	1.0500	11.2489	624.700	-70.010	7.000	5.200
22	Kano	1.0000	-33.2156	9.094	141.884	220.600	142.900
23	Shiroro	1.0500	-16.3875	388.900	425.078	70.300	36.100
24	Sapele	1.0500	9.0683	190.300	166.769	20.600	15.400
25	Calabar	1.0000	-17.0760	11.036	47.952	110.000	89.000
26	Katampe	1.0000	-20.6243	0.000	-0.000	290.100	145.000
27	Okpai	1.0500	7.0949	750.000	207.494	0.000	0.000
28	AES-GS	1.0500	7.4384	750.000	-40.677	0.000	3226.800
Total				**4749.071**	**2752.466**	**4604.500**	**3226.800**

Table 6: Tabulated results of line flows and losses with SSSC

From Bus	To Bus	P MW	Q MVAR	From Bus	To Bus	P MW	Q MVAR	Line Losses	
								MW	MVAR
1	3	275.046	207.345	3	1	-274.400	-202.611	0.646	4.735
1	5	754.969	243.623	5	1	-741.841	-143.158	13.129	100.465
1	28	-741.834	111.301	28	1	750.000	-14.327	8.166	96.974
2	7	298.372	12.725	7	2	-297.401	-5.525	0.971	7.200
2	8	371.628	45.416	8	2	-366.161	-5.113	5.467	40.303
4	5	-343.613	51.182	5	4	344.458	-45.148	0.845	6.034
5	8	-279.346	37.514	8	5	288.084	28.263	8.739	65.777
5	9	87.443	-10.062	9	5	-87.024	13.200	0.418	3.138

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

5	10	-35.887	5.268	10	5	36.018	-4.288	0.130	0.980
6	8	-13.800	31.387	8	6	13.883	-30.765	0.083	0.622
7	24	200.901	-46.903	24	7	-199.929	54.141	0.973	7.238
8	14	47.775	-19.211	14	8	-47.639	20.229	0.136	1.018
8	24	-366.881	-101.364	24	8	369.629	121.692	2.747	20.329
9	10	-181.872	29.948	10	9	183.401	-18.397	1.529	11.551
10	17	-409.355	-11.119	17	10	419.584	88.426	10.229	77.307
11	12	378.500	363.265	12	11	-376.004	-344.792	2.496	18.473
12	14	-430.745	73.909	14	12	441.738	9.450	10.992	83.359
12	25	379.749	26.956	25	12	-369.878	47.002	9.870	73.958
13	14	-166.665	-93.438	14	13	167.979	103.368	1.314	9.930
14	27	-746.678	-180.202	27	14	750.000	218.960	3.322	38.758
15	21	-114.500	-23.825	21	15	116.137	36.115	1.637	12.290
16	19	-119.727	22.629	19	16	121.479	-9.460	1.752	13.169
17	18	-494.536	-99.315	18	17	495.000	103.956	0.464	4.641
17	21	-494.241	81.364	21	17	501.563	-26.675	7.322	54.689
17	23	558.193	25.971	23	17	-530.853	179.359	27.339	235.330
19	20	42.370	-7.373	20	19	-42.279	7.876	0.091	0.503
19	25	-266.562	52.132	25	19	270.915	-19.451	4.353	32.681
20	22	215.708	-12.399	22	20	-211.506	44.144	4.202	31.745
20	23	-544.145	-64.255	23	20	555.553	149.518	11.408	85.263
23	26	293.900	154.530	26	23	-290.100	-126.129	3.800	28.402
Total								**144.571**	**1136.863**

IV. Discussions

The results of the simulations carried out on the Nigerian 28-bus network without SSSC and the impact of connecting the SSSC to the network in reducing power (active and reactive) losses and enhancing the weak bus voltages are presented and analyzed here. The SSSC was connected to the identified weak buses i.e bus 4, 5, 9, 10, 13, 16, 19, 20 and 22 operating in the voltage range of 0.9 ≤. X ≤ 1.1. Bus 1 (Egbin) is taken as the reference bus which caters for the losses in the other buses. Its phase angle is 0 (Zero). These results tabulated and plotted in these sections are corresponding values of each program obtained from the simulation of the developed Matlab program. The power flow solutions, line flows and losses were subsequently presented

From the results of the power flow study by Newton Ralphson iterative techniques, 10 (ten) buses were identified as weak buses since their voltages were below 1.0 p.u. They are bus 4(kangba), 5(Ikeja), 9(Ayode), 10(Oshogbo), 13(New Heaven), 16(Gombe), 19(Jos), 20(Kaduna), 22(Kano), and 25(Calabar). Hence after observing the various buses with weak voltage and high active and reactive power losses, SSSC was then inserted at these weak buses. i.e at buses 4, 5, 9, 10, 13, 16, 19, 20, 22, and 25 these are the potential buses where the SSSC FACTS device were applied to improve the voltages in order to maintain their voltage magnitudes at 1.0 P.U and also reduce their active and reactive power losses as shown in table 7. Thus it can be seen from the results in table7 below, that the presence of SSSC improved the voltages at the weak buses and also reduced the active and reactive power losses at these weak buses. Hence the presence of SSSC in the network improved the voltages thereby preventing voltage collapse and voltage sag as well as reduced the losses in the network and subsequently reduced the cost involved in the generation of energy.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

Table 7: Comparative voltage magnitudes of weak buses

Weak Bus NO.	Bus Name	Voltage Magnitude (P.U)	
		Without SSSC	With SSSC
4	AKANGBA	0.8776	1.3021
5	IKEJA	0.8951	1.1709
9	AYODE	0.8540	1.1982
10	OSHOGBO	0.9052	1.0143
13	NEW HEAVEN	0.9885	1.0217
16	GOMBE	0.7646	1.0610
19	JOS	0.8700	1.0018
20	KADUNA	0.8950	1.9943
22	KANO	0.7393	1.1402
25	CALABAR	0.9033	1.0474

Analysis of line flows and losses

From the results of the line flows and losses before the incorporation of SSSC presented in table 4. above, the lines with higher power (active and reactive) losses are lines 1-5 (32.792 MW, 250.933 MVAR), 10-17 (11.940 MW, 90.234 MVAR), 12-14 (12.606 MW, 95.598 MVAR), 12-25 (13.954 MW, 104.554 MVAR), 17-23 (33.886 MW, 254.495 MVAR), 20-22 (10.314 MW, 17. 927 MVAR) and 20-23 (22.692 MW, 169.594 MVAR) with line 17-23 having the maximum power (active and reactive) losses. However, when the SSSC was applied to the weak buses a drastic reduction of power (active and reactive) losses were noticed as shown in table 8 below. Line 17-23 (i.e. transmission line connecting bus 17 to bus 23) which has the maximum power losses of 33.886 MW, 254.495 MVAR before application of SSSC and which subsequently reduced to 27.339 MW, 205.330 MVAR after the incorporation of SSSC giving a percentage loss reduction in active power loss of 19.32% and thus active power saving of (100 – 19.32)% = 80.68% as shown in table 4.8a below. Also the total system active and reactive power losses obtained for the base case (i.e. without the incorporation of SSSC) are 205.183 MW and 1594.683 MVAR respectively. However, after the incorporation of the SSSC FACTS device at the weak buses the total system power (active and reactive) losses reduced to 144.571 MW and 1136.863MVAR respectively as shown in table 4.7, figs. 4.2a and 4.2b below. This gave a percentage loss reduction in active power loss of 29.54% and active power savings of (100 – 29.54) % = 70.46%. While the percentage loss reduction in reactive power loss is 28.71% giving a reactive power saving of (100 – 28.71) % = 71.29% as indicated in table 4.8b below. The above results shows that with the incorporation of SSSC in the power network, there was a considerable improvement in the voltage profile of the network and also an improvement of the voltages at the weak buses as well as active and reactive reduction of the power losses in the network which consequently helps in reducing the cost of energy generation in the network.

Advantages of SSSC

Compared to other fact controllers, SSSC eliminate the bulky passive components such as capacitors and inductors. They can also supply or absorb reactive power in addition to offering inductive and capacitive mode symmetrically and has the possibility of connecting an energy source on the DC side to exchange real power with the AC network.

A major drawback with SSSC is the need for a coupling transformer however, an intermediate transformer if multipulse converters are used. SSSC does not require any magnetic devices and the harmonics are better when controlled with SSSC.

Consequently, SSSC offers a high improvement both in the power (semiconductor) device characteristics and high reduction in the cost of energy supply.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

Table 8: Comparative Power losses of lines with higher losses

Transmission Lines	**Without SSSC**		**With SSSC**	
	Active (MW)	**Reactive (MVAR)**	**Active (MW)**	**Reactive (MVAR)**
1-5	32.792	250.933	13.129	100.465
10-17	11.940	90.234	10.229	77.307
12-14	12.606	95.598	10.992	83.359
12-25	13.954	104.554	9.870	73.959
17-23	33.886	254.495	27.339	205.330
20-22	10.314	77.927	4.202	31.745
20-23	22.692	169.594	11.408	85.263

Table 9: Comparative total active and reactive power losses of the network

Power Loss	**Without SSSC**	**With SSSC**
ACTIVE POWER (MW)	205.183	144.571
REACTIVE POWER (MVAR)	1594.683	1136.863

Table 10: Effects of SSSC in line 17-23

Power Loss	**%Reduction**
ACTIVE POWER (MW)	19.32
REACTIVE POWER LOSS (MVAR)	19.32

Table 10: Effects of SSSC in the total network system

Power Loss	**%Reduction With SSSC**
ACTIVE POWER (MW)	29.54
REACTIVE POWER L (MVAR)	28.71

V. Conclusion

In this research work a power flow analysis was carried out on the Nigerian 28-bus system network using Matlab software by Newton Raphson method and both the weak buses and the transmission lines connecting these weak buses were identified. Also the line with maximum power (active and reactive) losses was identified. The Static Synchronous Series Compensator (SSSC) device was then applied at the weak busses and its effect on the network for power loss reduction was demonstrated and compared with the base case scenario. It showed that the system losses were significantly reduced. The results indicated that the total system active and reactive power losses reduced by 29.54% and 28.71% respectively when SSSC was applied to the weak buses hence more active and reactive power was available in the network when compared to the base case due to the installation of SSSC. The maximum power (active and reactive) loss in the system without SSSC occurred in the transmission line connecting bus 17 (Jebba) to bus 23 (Shiroro) and 19.32% loss reduction was noticed on this line after the incorporation of SSSC. It was also observed that all the lines having higher power losses experienced significant loss reductions when the Static Synchronous Series Compensator was connected in the system.

Furthermore, the effect of the application of the SSSC device for enhancing the system voltage profile was clearly demonstrated. It showed an improvement in the magnitude of voltages at the weak buses and other load buses to maintain the voltages at 1.0 P.U. It is important to note here that the improvement in voltage and reduction in active power loss in the system was due to injection of voltage by the SSSC to compensate for the drop in voltage in the affected buses. Hence the main conclusions of this thesis are:

1. The placement of the SSSC device significantly mitigated the active and reactive power losses of the test system.
2. Almost all the bus voltages were enhanced as empirically determined.
3. The simple and direct method of placing the SSSC at the weak buses and in the lines having maximum power losses in the network has shown effective results in reducing the power losses and enhancing the voltage profile of the buses in the transmission lines.
4. Prevents voltage collapse as well as voltage sag
5. Improves the voltage supply and reduces the active and reactive power losses thereby reducing the cost involve in the generation of energy.

Reference

1. Aborisade, D.O., Adebayo, I.G. and Oyesina, K.A. (2014).A Comparism of Voltage Enhancement and Loss Reduction Capabilities of STATCOM and SSSC FACTS controllers.*American Journal of Engineering Research* (AJER), Vol. 03, Issue 01, Pp. 96-105.
2. Acha, E., Fuete-Esquiivel, C.R., Anbri-Perez, H. and Angeles-Camacho, C. (2004). FACTS Modeling and Simulation in Power Networks, John Wiley and Sons, West Sussex, UK.
3. Arrillaga, J. (1998). High voltage direct current transmission.Institute of Electrical Engineers, Second Edition, London.
4. Arrillaga, J. and Armold, C.P. (1990).Computer Analysis of Power Systems.Second Edition, John Wiley and Sons, Chichester.
5. Aswathi, K. D. and Sindhu, M.R. (2015).Application of Static Synchronous Series Compensator (SSSC) to Enhance Power Transfer Capability in IEEE Standard Transmission System.IJCTA, 8(5), Pp. 2029-2036, 2015, International Science Press.
6. Balasubba, M.R., Obulesh, Y.P. and Sivanag, R.S. (2012). Analysis and Simulation of Series FACTS Devices to minimize Transmission Loss and Generator Cost. *International Journal of Advances in Engineering and Technology*, Vol.2, Issue 1, Pp. 463-473.
7. Brown, H.E. (1975). Solution of Large Network by Metrix Methods, John Wiley and Sons, Chichester.
8. Elgerd, O. (1982). Electric Energy System Theory, An Introduction. Second Edition, McGraw-Hill, New York.
9. El-Zonkoly, A.M. (2006).Optimal Sizing of SSSC Controllers to Minimize Transmission Loss and a Novel Model of SSSC to Study Transient Response.World Academy of Sciences, Engineering and Technology 24, 2006.
10. Emad, A.D.,Verma, K. and Surya, P. (2013). Effect of BVSI in Static Synchronous Series Compensator (SSSC) for control of Active Power Flow in a Transmission Line.*International Journal of Electronic Communication and Computer Engineering*, Vol. 4, Issue 3.
11. Grainger, J.J. and Stevenson, W.D. (1968).Power System Analysis, Third Edition, McGraw-Hill, New York.
12. Hingoranni, N.G. and Gyugyi, L. (2000).Uderstanding Facts Concepts and Technology of Flexible AC Transmission Systems. Wiley-IEEE Press, New York, NY ISBN 0-7803-3464-7.
13. Hossein, N.A. (2011). Analysis of Static Synchronous Series Compensator (SSSC) on Congestion Management and Voltage Profile in Power System by PSAT Toolbox.*Research Journal of Applied Sciences, Engineering and Technology*, 3(7), 660-667.
14. Ibe, A.O. and Okedu, E.K. (2009).A Critical Review OF Grid Operation in Nigeria.*The Pacific Journal of Science and Technology*, Vol. 10, No. 2, Pp. 486-490.
15. Janhavi, C.G. and Ratnakar, K.L. (2015).Performance Analysis of an IEEE 9-bus System with TCSC and SSSC.*International Journal of Engineering Science Innovation Technology* (IJESIT), Vol. 4, Issue 3.
16. Jebaraj, L., Christober, C.A.R. and Irisappane, S. (2015). Voltage and Real Power Loss Analysis Incorporating CE-SSSC with VS-SVC Combination through Fruit Fly Optimizatin. WSEAS Transaction on Power System, Vol. 10. Available from: http//www.wseas.org/multimedia/journal/power/….
17. Jebaraj, L., Christober, C.A.R., Sriram, K., Ramesh, J. and Sivasankari, R. (2013). Static Synchronous Series Compensator and Static Var Compensator Interaction on Voltage Stability Limit Enhancement and Active Power Loss Minimization through *Differential Evolution Algorithm. Academic Journals*, Vol. 8(24), Pp. 112221-1132.
18. Jignesh, P. (2016). Electrical Engineering Portal.
19. Kannan, A.S. and Kayalvizhi, R. (2011). Utility of PSO for Loss minimization and Enhancement of Voltage Profile Using UPFC, *International Journal of Science and Engineering Research*, Vol. 2, Issue 2.
20. Kundur, P.P. (1994). Power System Stability and Control.Second Edition, McGraw-Hill, New York.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

21. Manase, L.C. (`998). Flexible AC Transmission System, Placement, Control and Interaction. Paper presented in an EPRI, NSF Workshop in Global Dynamic Optimiation.
22. MetinDogan, SalihTosun, Ali Ozturk and Kenan, D.M. (2011). Investigation of TCSC and SSSC controller on the Power System.ELECO 2011, 7th International Conference on Electrical and Electronics Engineering, 1-4, December 2011, Bursa, Turkey.
23. Mohan, N., Udeland,T.M. and Robbins, W.P. (1995). Power Electronic Converter Applications and Design, Second Edition.
24. Momoh, L.J., Din, S.X. Guo. And Adapa, R. (1995). Economic Operation and Planning of MultiArea